

TITLE OF THE INVENTION

VARIABLE GEOMETRY MIRROR HAVING HIGH-PRECISION, HIGH  
GEOMETRY CONTROLLABILITY

CROSS-REFERENCE TO RELATED APPLICATIONS

5           This application is based upon and claims the  
benefit of priority from the prior Japanese Patent  
Application No. 2001-282296, filed September 17, 2001,  
the entire contents of which are incorporated herein by  
reference.

10                           BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a variable  
geometry cylinder mirror and more particularly to a  
highly configurable, high precision cylindrically  
15 deformable variable geometry mirror.

2. Description of the Related Art

In the field of high-precision micro optical  
systems such as an optical pickup, a micro variable  
focus mirror capable of changing the curvature of its  
20 reflecting face has been proposed so as to aim at  
simplification of the structure for focusing, which  
conventionally uses an electromagnetic actuator.

Further, in a small image pickup optical system,  
miniaturization is largely dependant on the size of the  
25 variable focus mirror.

Adoption of micro electro-mechanical system (MEMS)  
technology in a variable focus mirror enables low-cost,

high-precision manufacturing thereof.

An example of the cylindrically deformable variable geometry cylinder mirror of this technology is a monolithic reflecting mirror apparatus disclosed in  
5 Jpn. Pat. Appln. KOKAI Publication No. 2-101402.

In this monolithic reflection mirror unit, as shown in FIG. 26, a metallic thin film 54, which serves as an electrode layer, is formed on a silicon  
10 semiconductor substrate 51, which acts as a fixed side electrode, through a silicon epitaxial layer 52 and a silicon oxide thin film 53. Window holes 56, 57 are formed in the silicon oxide thin film 53 and the metallic thin film 54 with a central portion 55 left between them.

15 Because the window holes 56, 57 communicate with each other through a vacant portion 58 formed in the silicon epitaxial layer 52, the central portion 55 is set up as a straddle-mounted type reflection mirror portion.

20 The straddle-mounted type reflection mirror portion 55 opposes the silicon semiconductor substrate 51 through the vacant portion 58. By applying a potential difference to 51 and 55, the reflection mirror portion 55 is distorted, thereby functioning as  
25 a variable geometry cylinder mirror.

However, although the variable geometry cylinder mirror employing the conventional monolithic type

reflection mirror unit can be so constructed as a small, low-cost variable geometry cylinder mirror, the electrostatic force applied to the reflection mirror portion cannot be changed according to each position.  
5 Thus, this variable geometry cylinder mirror cannot be deformed to an asymmetrical shape.

Further, the variable geometry cylinder mirror using the conventional monolithic type reflection mirror unit can only be changed from a flat face to a  
10 concave face and it cannot be deformed to a convex shape.

Additionally, because the center of the reflection mirror portion always drops with deformation of the variable geometry cylinder mirror using the  
15 conventional monolithic type reflection mirror unit, there is a problem that the curvature cannot be changed with the center portion fixed.

Further, the straddle mounted type structure is distorted by deformation of the reflection mirror  
20 portion. Thus, if a large distortion is desired, a high voltage is needed in order to produce a large electrostatic force.

#### BRIEF SUMMARY OF THE INVENTION

The present invention has been achieved in view of  
25 the above-described problems and therefore, an object of the present invention is to provide a small variable geometry cylinder mirror, the shape of which can be

freely set and can also be asymmetrical.

Another object of the present invention is to provide a variable geometry cylinder mirror, which can be deformed continuously from a concave  
5 face to a convex face and further which can be deformed with the center or any point of the reflection mirror fixed.

Still another object of the present invention is to provide a variable geometry cylinder mirror capable  
10 of obtaining large changes in curvature with a relatively low voltage.

In order achieve the above objects, according to a first aspect of the present invention, there is provided a variable geometry cylinder mirror  
15 comprising:

- a frame member;
- a flexible thin film in which two end portions opposing each other are supported by the frame member;
- a reflection surface which is provided on the  
20 flexible thin film and reflects light;
- a first electrode provided integrally with the flexible thin film;
- a second electrode substantially fixed to the frame member so as to oppose the first electrode on an  
25 opposite side of the reflection surface; and
- a third electrode substantially fixed to the frame member so as to oppose the first electrode on the same

side as the reflection surface,

wherein an optical opening to introduce light into the reflection surface is provided on the side of the reflection surface,

5           at least any one of the second and third electrodes is divided in the direction connecting the two end portions, and

the configuration of the reflection surface is controlled to a desired configuration by applying a  
10           desired voltage selectively to between the first electrode and the divided second or third electrode.

According to a second aspect of the present invention, there is provided a variable geometry cylinder mirror according to the first aspect, wherein  
15           the reflection surface of the flexible thin film is formed of metallic thin film and serves as the first electrode.

According to a second aspect of the present invention, there is provided a variable geometry  
20           cylinder mirror according to first aspect, wherein an openings are provided on both sides of the reflection surface in the flexible member across a straight line connecting the end portions supported by the frame member.

25           According to a fourth aspect of the present invention, there is provided a variable geometry cylinder mirror according to the first aspect, wherein

in a region between the end portion supported by the frame member and the reflection surface in the flexible thin film, stiffness thereof in the direction in which the second or third electrode is divided is decreased.

5           According to a fifth aspect of the present invention, there is provided a variable geometry cylinder mirror according to the fourth, wherein the region in which the stiffness of the flexible thin film is dropped is wave-like.

10           According to a sixth aspect of the present invention, there is provided a variable geometry cylinder mirror according to the fifth aspect, wherein the flexible thin film is composed of overlaid layers of metallic thin film and silicon nitride or metallic  
15 thin film and silicon oxide.

          According to a seventh aspect of the present invention, there is provided a variable geometry cylinder mirror according to the fourth aspect, wherein  
20 as for the sectional area of the flexible thin film in a direction perpendicular to the direction in which the second or third electrode is divided, that of the region in which the stiffness of the flexible thin film is dropped is smaller than that of a region  
corresponding to the reflection surface.

25           According to an eighth aspect of the present invention, there is provided variable geometry cylinder mirror according to the fourth aspect, wherein an

opening or a cutout is provided in the region in which the stiffness of the flexible thin film is dropped.

According to a ninth aspect of the present invention, there is provided a variable geometry cylinder mirror according to the first aspect, wherein the flexible thin film is composed of overlaid layers of metallic thin film and polymer material thin film.

According to a tenth aspect of the present invention, there is provided a variable geometry cylinder mirror according to the seventh aspect, wherein the flexible thin film is composed of overlaid layers of metallic thin film and polymer material thin film.

According to an eleventh of the present invention, there is provided a variable geometry cylinder mirror according to the eighth aspect, wherein the flexible thin film is composed of overlaid layers of metallic thin film and polymer material thin film.

According to a twelfth aspect of the present invention, there is provided a variable geometry cylinder mirror according to the first aspect, wherein the third electrode and a supporting member thereof are provided outside the optical opening.

According to a thirteenth aspect of the present invention, there is provided a variable geometry cylinder mirror according to the first aspect, wherein the third electrode is disposed within the optical

opening while the third electrode disposed within the optical opening and the supporting member thereof have property allowing light to be transmitted through.

According to a fourteenth aspect of the present invention, there is provided a variable geometry cylinder mirror comprising:

a frame member;

a flexible thin film in which two end portions opposing each other are supported by the frame member;

a reflection surface which is provided on the flexible thin film and reflects light;

a first electrode provided integrally with the flexible thin film; and

a second electrode substantially fixed to the frame member so as to oppose the first electrode on an opposite side of the reflection surface, the second electrode being divided in the direction connecting the two end portions,

wherein the configuration of the reflection is controlled to a desired configuration by applying a desired voltage selectively to between the first electrode and the divided second or third electrode.

According to a fifteenth aspect of the present invention, there is provided a variable geometry cylinder mirror according to the fourteenth aspect, wherein the reflection surface of the flexible thin film is formed of metallic thin film and serves as the



first electrode.

According to a sixteenth aspect of the present invention, there is provided a variable geometry cylinder mirror according to the fourteenth aspect, wherein an openings are provided on both sides of the reflection surface in the flexible member across a straight line connecting the end portions supported by the frame member.

According to a seventeenth aspect of the present invention, there is provided a variable geometry cylinder mirror according to the fourteenth aspect, wherein in a region between the end portion supported by the frame member and the reflection surface in the flexible thin film, stiffness thereof in the direction in which the second electrode is divided is decreased.

According to an eighteenth aspect of the present invention, there is provided a variable geometry cylinder mirror according to the seventeenth aspect, wherein the region in which the stiffness of the flexible thin film is dropped is wave-like.

According to a nineteenth aspect of the present invention, there is provided a variable geometry cylinder mirror according to the eighteenth aspect, wherein the flexible thin film is composed of overlaid layers of metallic thin film and silicon nitride or metallic thin film and silicon oxide.

According to a twentieth aspect of the present

invention, there is provided a variable geometry  
cylinder mirror according to the seventeenth aspect,  
wherein as for the sectional area of the flexible thin  
film in a direction perpendicular to the direction in  
5 which the second electrode is divided, that of the  
region in which the stiffness of the flexible thin film  
is dropped is smaller than that of a region  
corresponding to the reflection surface.

According to a twenty-first aspect of the present  
10 invention, there is provided a variable geometry  
cylinder mirror according to the seventeenth aspect,  
wherein an opening or a cutout is provided in the  
region in which the stiffness of the flexible thin film  
is dropped.

15 According to a twenty-second aspect of the present  
invention, there is provided a variable geometry  
cylinder mirror according to the fourteenth aspect,  
wherein the flexible thin film is composed of overlaid  
layers of metallic thin film and polymer material thin  
20 film.

According to a twenty-third aspect of the present  
invention, there is provided a variable geometry  
cylinder mirror according to the twentieth aspect,  
wherein the flexible thin film is composed of overlaid  
25 layers of metallic thin film and polymer material thin  
film.

According to a twenty-fourth aspect of the present

invention, there is provided a variable geometry  
cylinder mirror according to the twenty-first aspect,  
wherein the flexible thin film is composed of overlaid  
layers of metallic thin film and polymer material thin  
5 film.

According to a twenty-fifth aspect of the present  
invention, there is provided a variable geometry  
cylinder mirror according to the first aspect, wherein  
the flexible thin film having the frame member, the  
10 reflection surface and the first electrode is  
manufactured by:

a diffused layer forming step of forming a  
diffused layer having a predetermined shape of a  
conductive type in a first main face of a mono-crystal  
15 silicon substrate of another conductive type;

a thin film laminating step of laminating a thin  
film on the first main face of the mono-crystal silicon  
substrate;

an etching step of, with a predetermined voltage  
20 applied to the diffused layer of the conductive type,  
carrying out electrochemical etching from a second main  
face in etching solution; and

a cutting and separating step of cutting and  
separating frame-like mono-crystal silicon which is  
25 part of the mono-crystal silicon substrate form  
portions corresponding to the flexible thin film and  
the frame member.

According to a twenty-sixth aspect of the present invention, there is provided a variable geometry cylinder mirror according to the fourteenth aspect, wherein the flexible thin film having the frame member, the reflection surface and the first electrode is  
5 manufactured by:

a diffused layer forming step of forming a diffused layer having a predetermined shape of a conductive type in a first main face of a mono-crystal silicon substrate of another conductive type;  
10

a thin film laminating step of laminating a thin film on the first main face of the mono-crystal silicon substrate;

an etching step of, with a predetermined voltage applied to the diffused layer of the conductive type, carrying out electrochemical etching from a second main face in etching solution; and  
15

cutting and separating step of cutting and separating frame-like mono-crystal silicon which is part of the mono-crystal silicon substrate form portions corresponding to the flexible thin film and the frame member.  
20

According to a twenty-seventh aspect of the present invention, there is provided a variable geometry cylinder mirror according to the fifth aspect, wherein the flexible thin film having the frame member, the reflection surface and the first electrode is  
25

manufactured by:

a groove forming step of forming parallel grooves  
in a first main face of a flat substrate;

5 a thin film forming step of forming a thin film on  
the first main face of the substrate;

an etching step of etching until the thin film  
formed in the thin film forming step is exposed from a  
second main face of the substrate; and

10 a cutting and separating step of cutting and  
separating a frame-like portion which is part of the  
substrate from portions corresponding to the flexible  
thin film and the frame member.

According to a twenty-eighth aspect of the present  
invention, there is provided a variable geometry  
15 cylinder mirror according to the eighteenth aspect,  
wherein the flexible thin film having the frame member,  
the reflection surface and the first electrode is  
manufactured by:

20 a groove forming step of forming parallel grooves  
in a first main face of a flat substrate;

a thin film forming step of forming a thin film on  
the first main face of the substrate;

25 an etching step of etching until the thin film  
formed in the thin film forming step is exposed from a  
second main face of the substrate; and

a cutting and separating step of cutting and  
separating a frame-like portion which is part of the

substrate from portions corresponding to the flexible thin film and the frame member.

Additional objects and advantages of the invention will be set forth in the description which follows, and in part will be obvious from the description, or may be learned by practice of the invention. The objects and advantages of the invention may be realized and obtained by means of the instrumentalities and combinations particularly pointed out hereinafter.

10 BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate presently preferred embodiment of the invention, and together with the general description given above and the detailed description of the preferred embodiment given below, serve to explain the principles of the invention.

20 FIGS. 1A and 1B are perspective views of an upper face and a lower face showing the entire structure of a variable geometry cylinder mirror according to a first embodiment of the present invention;

FIGS. 2A and 2B are perspective views of an upper face and a lower face showing a bottom substrate 101 of the variable geometry cylinder mirror according to the first embodiment of the present invention;

25 FIGS. 3A and 3B are perspective views of an upper face and a lower face showing an intermediate substrate

102 of the variable geometry cylinder mirror according to the first embodiment of the present invention;

FIGS. 4A and 4B are perspective views of an upper face and a lower face showing a top substrate 103 of the variable geometry cylinder mirror according to the first embodiment of the present invention;

FIGS. 5A and 5B are enlarged views taken in the direction of an arrow A and an arrow B shown in FIG. 1A;

FIG. 6 is a sectional view parallel to a slit-like opening portion 104 in a region in which a lower electrode 109 and an upper electrode 117 oppose each other for explaining the operation of the variable geometry cylinder mirror according to the first embodiment of the present invention;

FIG. 7 is a top view of the intermediate substrate 102 for explaining the method of manufacturing the intermediate substrate of the variable geometry cylinder mirror according to the first embodiment of the present invention;

FIGS. 8A and 8B are a sectional view taken along the line 8A-8A and a sectional view taken along the line 8B-8B in FIG. 7;

FIGS. 9A and 9B are a sectional view taken along the line 9A-9A and a sectional view taken along the line 9B-9B in FIG. 7;

FIGS. 10A and 10B are a sectional view taken along

the line 10A-10A and a sectional view taken along the line 10B-10B in FIG. 7;

FIGS. 11A and 11B are perspective views of an upper face and a lower face showing an intermediate substrate 201 of a variable geometry cylinder mirror according to a second embodiment of the present invention;

FIG. 12 is a sectional view taken along the line 12-12 in FIG. 11A;

FIG. 13 is a sectional view for explaining a method of manufacturing an intermediate substrate 201 of the variable geometry cylinder mirror according to the second embodiment of the present invention;

FIG. 14 is a sectional view for explaining the method of manufacturing the intermediate substrate 201 of the variable geometry cylinder mirror according to the second embodiment of the present invention;

FIG. 15 is a sectional view for explaining the method of manufacturing the intermediate substrate 201 of the variable geometry cylinder mirror according to the second embodiment of the present invention;

FIG. 16 is a sectional view for explaining the method of manufacturing the intermediate substrate 201 of the variable geometry cylinder mirror according to the second embodiment of the present invention;

FIG. 17 is a sectional view for explaining the method of manufacturing the intermediate substrate 201



of the variable geometry cylinder mirror according to the second embodiment of the present invention;

FIG. 18 is a sectional view for explaining the method of manufacturing the intermediate substrate 201 of the variable geometry cylinder mirror according to the second embodiment of the present invention;

FIG. 19 is a sectional view for explaining the method of manufacturing the intermediate substrate 201 of the variable geometry cylinder mirror according to the second embodiment of the present invention;

FIGS. 20A and 20B are perspective views of an upper face and a lower face showing an intermediate substrate 400 of a variable geometry cylinder mirror according to a third embodiment of the present invention;

FIGS. 21A and 21B are perspective views of an upper face and a lower face showing a top substrate 501 of a variable geometry cylinder mirror according to a fourth embodiment of the present invention;

FIGS. 22A and 22B are perspective views of an upper face and a lower face showing a bottom substrate 108 of a variable geometry cylinder mirror according to a fifth embodiment of the present invention;

FIGS. 23A and 22B are perspective views of an upper face and a lower face showing a top substrate 608 of the variable geometry cylinder mirror according to a fifth embodiment of the present invention;

FIGS. 24A and 24B are perspective views of an upper face and a lower face showing a bottom substrate 801 of a variable geometry cylinder mirror according to a sixth embodiment of the present invention;

5           FIGS. 25A and 25B are enlarged views taken in the direction of an arrow A and an arrow B in FIG. 24A; and

          FIG. 26 is a perspective view showing the main structure of a monolithic type reflection mirror unit disclosed in Jpn. Pat. Appln. KOKAI Publication  
10       No. 2-101402 as an example of a conventional variable geometry cylinder mirror which is deformed cylindrically.

#### DETAILED DESCRIPTION OF THE INVENTION

          Reference will now be made in detail to the  
15       preferred embodiments of the invention as illustrated in the accompanying drawings, in which like reference numerals designate like or corresponding parts.

          Hereinafter, the preferred embodiments of the present invention will be described with reference to  
20       the accompanying drawings.

(First embodiment)

          A variable geometry cylinder mirror according to a first embodiment of the present invention will be described with reference to FIGS. 1A, 1B to 10A, 10B.

25       FIGS. 1A and 1B are perspective views of an upper face and a lower face showing the entire structure of the variable geometry cylinder mirror according to the

first embodiment of the present invention.

The variable geometry cylinder mirror is constituted of three layers: a bottom substrate 101, an intermediate substrate 102 and an top substrate 103, disposed with a constant space specified by each spacer.

The top substrate 103 has a slit-like opening portion 104 formed therein, for introducing light.

As evident from the same Figure, the bottom substrate 101 and the top substrate 103 are projected with respect to the intermediate substrate 102 in opposite directions.

A lower electrode pad 105 is formed on a projected portion of the bottom substrate 101.

An upper electrode pad 106 and an intermediate electrode pad 107 are formed on a projected portion of the top substrate 103.

FIGS. 2A and 2B are perspective views of an upper face and a lower face showing the bottom substrate 101.

The bottom substrate 101 is made of mono-crystal silicon substrate 108 having a thickness of 300  $\mu\text{m}$ , and has a plurality of lower electrodes 109 disposed symmetrically across a region opposing the slit-like opening portion 104 formed in the top substrate 103. The lower electrode pads 105 and connection spacers 110 have a height of 30  $\mu\text{m}$  relative to the top substrate 103.

The silicon substrate 108 has a wiring layer which connects the respective lower electrodes 109 and lower electrode pads 105 through an interlayer insulating film and contact holes (not shown).

5           Such multi-layer electrodes and wiring can be formed easily on the silicon substrate 108 using ordinary integrated circuit manufacturing technology.

FIGS. 3A and 3B are perspective views of upper face and lower face showing the intermediate  
10           substrate 102.

          This intermediate substrate 102 has a flexible thin film 112 formed on a mono-crystal silicon substrate 111 having the thickness of 20  $\mu\text{m}$ , the flexible thin film 112 being comprised of polyamide  
15           film 1  $\mu\text{m}$  thick and Au/Cr overlaid film 50  $\mu\text{m}$  thick.

          The flexible thin film 112 is exposed to an opposite side of the mono-crystal substrate 111 as Au, acting as reflection faces.

          A rectangular opening portion 113 and a cutout  
20           portion 114 are formed in the mono-crystal silicon substrate 111, through which the flexible thin film 112 is exposed, the mono-crystal silicon substrate 111 being deformable with a slight stress.

          Cutouts 115 are formed in the flexible thin film  
25           112 along two side ends parallel to the slit-like opening portion 104 in the top substrate 103, in the opening portion 113. The flexible thin film 112 is

like a belt supported by two sides perpendicular to the slit-like opening portion 104 in the top substrate 103.

FIGS. 4A and 4B are perspective views of an upper face and a lower face showing the top substrate 103.

5           This top substrate 103 is made of a mono-crystal silicon substrate 116 having a thickness of 300  $\mu\text{m}$ , a plurality of upper electrodes 117 disposed in the form of a belt symmetrically with respect to the slit-like opening portion 104, the upper electrode pad 106, the  
10           intermediate electrode pad 107, an intermediate electrode lead-out electrode 118, a connecting spacer 120 having a height of 30  $\mu\text{m}$  to the bottom substrate 101 and a connecting spacer 121 having a height of 30  $\mu\text{m}$  to the intermediate substrate 102.

15           The silicon substrate 116 contains wiring layer (not shown) which connects the respective upper electrodes 117, intermediate electrode lead-out electrode 118, upper electrode pad 106 and intermediate electrode pad 107 through an interlayer insulating film  
20           and contact holes (not shown).

Such multi-layer electrodes and wiring can be formed easily on the silicon substrate 116 using ordinary integrated circuit manufacturing technology.

25           The slit-like opening portion 104 can be formed easily by using technology applied to ordinary MEMS device such as anisotropic etching for silicon using strong alkali solution.

Next, connection of the bottom substrate 101, intermediate substrate 102 and top substrate 103 will be described with reference to FIGS. 5A and 5B.

FIGS. 5A and 5B are enlarged views taken in the direction of arrows A and B in FIG. 1A.

That is, in these diagrams, its vertical directions are enlarged to facilitate understanding.

The connecting spacer 110 of the bottom substrate 101 is connected with the connecting spacer 120 of the top substrate 103.

Because the height of each of the connecting spacer 110 and connecting spacer 120 is 30  $\mu\text{m}$ , the bottom substrate 101 and the top substrate 103 oppose each other with a gap of 60  $\mu\text{m}$ .

The intermediate substrate 102 is connected with the top substrate 103 through the connecting spacer 121.

The height of the connecting spacer 121 is 30  $\mu\text{m}$  like the connecting spacer 110 and connecting spacer 120.

Consequently, the flexible thin film 112 on the intermediate substrate 102 is located substantially in the middle of the gap between the bottom substrate 101 and the top substrate 103.

Various kinds of materials can be considered as raw material for the respective connecting spacers 110, 120, 121. If easiness of manufacturing is taken into

account, particularly, material which can be fused with heat and patterned by photolithography method is preferred.

5       An Au bump 119 having the height of 40  $\mu\text{m}$  formed on the intermediate electrode lead-out electrode 118 on the top substrate 103 opposes substantially the center of the rectangular opening portion 113 and cutout 114 formed in the mono-crystal silicon substrate 111 of the intermediate substrate 102. Because the height of this  
10       Au bump 119 is slight larger than that of the connecting spacer 121 of the intermediate substrate 102, the flexible thin film 112 is pushed up by this portion. As a result, the Au bump 119 is electrically connected to the intermediate electrode pad 107 through  
15       the intermediate electrode lead-out electrode 118 on the top substrate 103 because metallic film is exposed on the surface of the flexible thin film 112.

      At this time, the flexible thin film 112 is deformed in the region of the cutout 114. However, the  
20       deformation of the flexible thin film 112 in the region of the cutout 114 never affects the flexible thin film 112 in the region of the opening portion 113 because the flexible thin film 112 is separated by the silicon thin plate 111 having a sufficiently higher stiffness  
25       than the flexible thin film 112.

      Because the lower electrode pad 105 and the upper electrode pad 106 correspond to the lower electrode 109

and the upper electrode 106, respectively while the flexible thin film 112 is connected to the intermediate electrode pad 107, if an external lead wire is connected to the electrode pads 105, 106, 107 so as to connect them to independent power supplies, independent voltage can be applied to each of the flexible thin film 112, the lower electrode 109 and the upper electrode 117.

Next, the operation of the variable geometry cylinder mirror of this embodiment will be described with reference to FIG. 6.

FIG. 6 shows a sectional view parallel to the slit-like opening portion 104 in the region in which the lower electrode 109 and the upper electrode 117 oppose each other.

If the flexible thin film 112, all the lower electrodes 109 and all the upper electrodes 117 are grounded, the flexible thin film 112 turns into a flat shape as indicated with dotted line in the same Figure. If a high voltage is applied to the upper electrodes 117-1, 117-2, 117-5, 117-6 and the lower electrodes 109-3, 109-4 while the flexible thin film 112, the upper electrodes 117-3, 117-4 and the lower electrodes 109-1, 109-2, 109-5, 109-6 are grounded, the flexible thin film turns to an indicated wave-like shape.

If the voltage applied to the upper electrodes 117-1, 117-2 is slightly higher than that applied to



the upper electrodes 117-5, 117-6, an asymmetrical deformation shape with respect to the center can be obtained as indicated in the same Figure.

5 By adjusting the voltage applied to the lower electrodes 109 and the upper electrode 117, the flexible thin film 112 can be deformed into any shape.

10 According to this embodiment, although no electrode for activating electrostatic force is formed just below the region of the top substrate in which the slit-like opening portion 104 is formed, its influence can be reduced to a level which can be neglected by increasing the width of the top electrode 117 and the bottom electrode 109 so as to be much larger than the width of this region.

15 Additionally, according to this embodiment, power consumption can be kept very low by using an electrostatic force for driving and because the structure is simple, it can be miniaturized.

20 Further, this embodiment enables deformation to both a concave shape and a convex shape and driving force can be controlled independently for each region opposing the electrode. Therefore, for example, the flexible thin film can be changed from the concave face to the convex face without deflecting the center of the mirror or any one point vertically by controlling the  
25 distribution of the driving force appropriately.

This feature cannot be acquired from an air

pressure type variable geometry mirror.

Further, because light enters directly into the flexible thin film 112 which acts as a reflection surface through the slit-like opening portion 104, no glass face or the like exists between incident light and the reflection surface. Thus, there is no loss of light beam, change in beam path length or deterioration of focusing performance.

Although according to this embodiment, the upper electrode 117 and the lower electrode 109 are divided substantially into six equal sections, needless to say, the number of electrodes may be changed or the electrodes may be divided unequally depending on a desired configuration or accuracy.

Next, the method of manufacturing the intermediate substrate of the variable geometry cylinder mirror of this embodiment will be described with reference to FIGS. 7 to 10B.

FIG. 7 shows a top view of the intermediate substrate 102. Sections 8A-8A, 9A-9A and 10A-10A in FIG. 7 will be described with reference to FIGS. 8A, 9A and 10A.

Further, the sections 8B-8B, 9B-9B and 10B-10B in FIG. 7 will be described with reference to FIGS. 8B, 9B and 10B.

As shown in FIGS. 8A and 8B, an N-type impurity diffused layer 123 is formed in a P-type low density

semiconductor substrate (mono-crystal semiconductor substrate) 122.

A silicon nitride film 124 is formed on both faces of the P-type low density semiconductor substrate (mono-crystal semiconductor substrate) 122.

An opening pattern larger than the intermediate substrate 102 is formed on the rear side of the silicon nitride film 124.

If viewed from above, the region in which the N type impurity diffused layer 123 is formed is substantially equal to the region of the intermediate substrate 102 in which the mono-crystal silicon substrate 111 is formed.

Further, it is preferable if the silicon nitride film 124 imparts a small stress on the silicon substrate 122, by appropriately controlling the composition of that film.

Next, a polyimide film 125 having a thickness of 1  $\mu\text{m}$  and a metallic film 126 having a thickness of 0.1  $\mu\text{m}$  are formed successively on the silicon nitride film 124.

Then, the metallic film 126 is patterned.

The metallic film 126 and the polyimide film 125 are removed by patterning in the region of the cutout 115 shown in FIG. 7.

Preferably, a very thin chrome thin film is formed between the polyimide film 125 and the metallic thin

film 126, thus adhesion of the metallic film 126 is improved.

Prior to formation of the metallic film 126, a contact hole 127 is formed in the polyimide film 125 and the silicon nitride film 124 on the front surface, so that the metallic film 126 is electrically conductive with the N-type impurity diffused layer 123.

Next, as shown in FIGS. 9A and 9B, with the front surface protected by mechanical sealing or the like, electrochemical etching is carried out with a strong alkali solution by applying a positive voltage to the metallic thin film 126.

Because the metallic film 126 is conductive with the N-type impurity diffused layer 123, etching is progressed in the region in which the silicon nitride film 124 on the front surface is removed by patterning until the silicon nitride film 124 on the front surface is exposed with the region of the N-type impurity diffused layer 123 left.

Next, as shown in FIGS. 10A and 10B, the silicon nitride film on the exposed suction face on the rear side and front side is removed by reactive ion etching from the rear side.

By cutting out the polyimide film 125 along the outer shape of the left N-type impurity diffused layer 123 according to excimer laser aberration or the like, the intermediate substrate 102 is obtained.

Although this embodiment indicates one manufacturing method of the intermediate substrate, it is needless to say that actually, a plurality of the intermediate substrates are obtained from one silicon wafer.

According to this method of manufacturing the intermediate substrate, as it can be formed in a completely monolithic way according to ordinary semiconductor manufacturing technology and MEMS technology, excellent productivity and safety are ensured.

Particularly, the manufacturing method of this embodiment in which the flexible thin film is formed on a thick solid substrate while the substrate is turned into thin film by electrochemical etching is preferable for an application requiring a high accuracy reflection surface in that there is no distortion accompanying a machining process for a frame member.

(Second embodiment)

A second embodiment of the present invention will be described with reference to FIGS. 11A to 19.

This embodiment is different from the first embodiment only in the intermediate substrate.

FIGS. 11A and 11B are perspective views of an upper face and a lower face showing the structure of an intermediate substrate 201 of a variable geometry cylinder mirror according to the second embodiment of

the present invention.

Basically, the intermediate substrate 201 of this embodiment has the same configuration as the intermediate substrate 102 of the first embodiment shown in FIGS. 3A and 3B. A flexible thin film 203 comprising silicon nitride film 400 nm thick and metallic thin film 50 nm thick is formed on the top face of a thin mono-crystal silicon substrate 202 having the thickness of 20  $\mu$ m which serves as a frame member.

Here it is assumed that the metallic thin film is exposed to the top face.

In the same manner as in the first embodiment, a rectangular opening portion 204 and a cutout 205 are formed in the mono-crystal silicon substrate 202 and a belt-like flexible thin film 203 is exposed in this portion and deformable with a slight stress.

Like the first embodiment, in the opening portion 204, cutouts 206 are formed in the flexible thin film 203 on its ends along two sides parallel to the slit-like opening 104 in the top substrate 103 and the flexible thin film 203 is shaped in the form of a belt supported by two sides perpendicular to the slit-like opening 104 in the top substrate 103.

A wave-like portion 207 of the flexible thin film 203 is formed near the two sides supporting the flexible thin film 203.

Next, FIG. 12 shows a section taken along the line 12-12 in FIG. 11A.

The flexible thin film 203 constructs the wave-like portion 207 in the vicinity of its sides supported by the thin mono-crystal silicon substrate 202 which acts as a frame member.

The variable geometry cylinder mirror of this embodiment is driven in the same manner as the variable geometry cylinder mirror of the first embodiment shown in FIG. 6. Because both the ends of the flexible thin film 203 are constructed in the form of a wave, it is expanded or contracted easily through this portion. Thus, if material having a large longitudinal elastic modulus like silicon nitride film is utilized as the flexible thin film 203 in the variable geometry cylinder mirror of the first embodiment, a relatively large deflection can be secured even when a high voltage is not applied to the same upper electrode 117 or lower electrode 109 as in the variable geometry cylinder mirror of the first embodiment.

That is, the mechanical properties of the silicon nitride film only slightly change over time, and its stiffness remains substantially high. This embodiment is preferable for long term use in high temperature and humidity environments.

Preferably, the wave-like portion 207 is located near the end portion, away from direct light.

Although in this embodiment, the wave-like portion 207 is provided on both end portions, it is needless to say that it could be provided on one side only.

5       Next, a method of manufacturing the intermediate substrate 201 of the variable geometry cylinder mirror according to the second embodiment of the present invention will be described with reference to FIGS. 13 to 16.

10       A silicon nitride film is formed on both faces of an overlay type SOI substrate in which as shown in FIG. 13, a mono-crystal silicon active layer 303 having a thickness of 20  $\mu\text{m}$  is bonded to a mono-crystal silicon substrate 301 having a face bearing of  $\langle 100 \rangle$ , 500  $\mu\text{m}$  thick through a silicon oxide film 302.

15       Then, upper and rear face silicon nitride films 304 and 305 are formed by patterning.

20       Next, as shown in FIG. 14, the mono-crystal silicon active layer 303 is patterned by reactive ion etching with the upper face silicon nitride pattern 304 as a mask. Consequently, a thin silicon region corresponding to the frame member 202 is formed as shown in FIG. 12.

25       Next, as shown in FIG. 15, an opening portion 306 is formed in the exposed silicon oxide film 302 with ordinary photolithography technology.

      Next, as shown in FIG. 16, anisotropic etching is carried out in the opening portion 306 up to 2  $\mu\text{m}$  with



tetramethyl ammonium hydroxide (YMAH) with the rear face protected and the silicon oxide film 302 as a mask, so that a depression 307 is formed.

Next, as shown in FIG. 17, the exposed silicon oxide film 302 is removed by hydrogen fluoride acid.

Next, as shown in FIG. 18, a silicon nitride film 308 is formed on the top face according to the chemical vapor deposition (CVD) method.

At this time, at a portion in which the dent portion 307 is formed, the silicon nitride film 308 is turned to a wave-like portion 309.

Next, as shown in FIG. 19, with the front face protected and the silicon nitride film pattern 305 as a mask, the silicon substrate 301 is etched until the silicon nitride film 308 is exposed.

After that, the thin mono-crystal silicon substrate 202 is cut out along its outer periphery as a frame member shown in FIG. 12 and the intermediate substrate 201 is formed by depositing Au/Cr thin film on an opposite side to the thin mono-crystal silicon substrate 202 of the silicon nitride film 308.

According to the method of manufacturing the intermediate substrate of this embodiment, the stabilized fine wave-like structure can be achieved by using the ordinary MEMS technology, because steps of forming a groove in the mono-crystal silicon substrate 301 according to the photolithography technology,

forming the silicon nitride film equally along this configuration and then removing the substrate after that, are adopted.

Although the active layer of the SOI substrate is  
5 used as the frame member of the intermediate substrate,  
a thin mono-crystal silicon forming step may be adopted  
by using electrochemical etching, in the same manner as  
in the first embodiment.

According to the method of manufacturing the  
10 intermediate substrate of this embodiment, the  
substrate cost is higher than the method of using  
electrochemical etching, and the flatness achieved on  
the substrate is slightly worse. However, because the  
step of forming the diffused layer can be omitted, the  
15 device can be produced in less time.

(Third embodiment)

A third embodiment will be described with  
reference to FIGS. 20A and 20B. This embodiment is  
different from the first embodiment only in the  
20 structure of the intermediate substrate.

FIGS. 20A and 20B are perspective views of an  
upper face and a lower face showing an intermediate  
substrate 400 of a variable geometry cylinder mirror  
according to the third embodiment of the present  
25 invention.

Although basically this intermediate substrate 400  
has the flexible thin film 112 composed of mainly

polyimide film like the first embodiment, a plurality of circular opening portions 401 are formed in the vicinity of sides supported by the thin mono-crystal silicon 111.

5           This circular opening portion 401 may be formed by using a photolithography method at the same time when the cutout 115 is formed.

          This method does not increase the quantity of steps, as compared to the first embodiment.

10           According to this embodiment, stiffness in the vicinity of the side supported side of the flexible thin film 112 is reduced by the circular opening portion 401, so that expansion/contraction are enabled by a smaller electrostatic attracting force. As a  
15           result, the driving voltage can be reduced as compared to the first embodiment.

          According to this embodiment, the plurality of circular opening portions 401 are provided to achieve low stiffness in part of the flexible thin film 112.  
20           Needless to say, the shape of this opening portion 401 may be formed in various ways such as rectangular shape, slit, etc.

          The same effect can be obtained by providing a U-like cutout or partially thinning, as well as by  
25           using a complete opening shape.

          That is, by setting smaller the sectional area used for achieving low stiffness in the flexible thin

film than the other portions, the stiffness may be adjusted just at a desired portion.

(Fourth embodiment)

5 A fourth embodiment will be described with reference to FIGS. 21A and 21B.

This embodiment is different from the first embodiment only in the structure of the top substrate.

10 FIGS. 21A and 21B are perspective views of an upper face and a lower face showing the structure of an upper substrate 501 according to the fourth embodiment of the present invention.

The structure of this top substrate 501 is similar to that of the top substrate 103 of the first embodiment, but different in that a quartz substrate 15 501 is used as the substrate and the slit-like opening portion 104 is omitted.

Because no electrode is formed in a region irradiated with incident light if the substrate is constructed of a transparent quartz, the incident light 20 can reach the intermediate substrate having a reflection surface, without providing with any opening.

A portion indicated by dotted line in FIGS. 21A and 21B is a region through which light enters the flexible thin film.

25 That is, according to this embodiment, by forming a substrate located in the region irradiated with the incident light of transparent quartz without providing

the top substrate with any opening, an optical opening can be secured.

Although in this embodiment, focusing performance is affected by an influence of distortion of the quartz substrate 501, particularly, this embodiment does not  
5 suit to high precision applications. However it is preferable for an application demanding for reduction of cost because the manufacturing method can be simplified.

10 In the meantime, needless to say, any other material may be used instead of quartz as long as it allows light through it.

(Fifth embodiment)

A fifth embodiment will be described with  
15 reference to FIGS. 22A, 22B, 23A and 23B.

This embodiment is different from the first embodiment in the structures of the bottom substrate and the top substrate.

FIGS. 22A and 22B are perspective views of an  
20 upper face and a lower face showing the structure of a bottom substrate 508 of a variable geometry cylinder mirror according to the fifth embodiment of the present invention.

According to the first embodiment shown in  
25 FIGS. 2A and 2B, no electrode is formed just below a light receiving portion while the lower electrodes 109 are disposed symmetrically on both sides of this

region. However, according to this embodiment, top electrodes are formed such that the electrodes on both sides are combined.

FIGS. 23A and 23B are perspective views of an  
5 upper face and a lower face showing the structure of a top substrate 608 of the variable geometry cylinder mirror according to a fifth embodiment of the present invention.

As for the top substrate 608, as shown in  
10 FIGS. 23A and 23B, that substrate is the same transparent quartz substrate 608 same as in the fourth embodiment, the electrode is composed of a transparent ITO and the upper electrodes 602 are disposed on the light receiving portion also.

15 A portion indicated with dotted line in FIGS. 23A and 23B is a region through which light enters the flexible thin film.

In the same manner as in the fourth embodiment, this embodiment adopts a light transparent material for  
20 a substrate and electrodes which light enters and secures an optical opening in order to make light enter into the flexible thin film.

According to this embodiment, a plurality of electrodes are disposed on both faces opposing the  
25 flexible thin film on the intermediate substrate. Because the top substrate and the upper electrodes are formed of a transparent material, the electrodes can be

disposed just over a light receiving portion of the top substrate.

According to this embodiment, beam path length changes depending on the position of the incident light and focusing performance deteriorate because the quartz  
5 substrate 608 and the upper electrodes 602 exist between incident light and a light receiving position. However, this is preferable for a case where the width of the incident light is large or positioning of a  
10 variable geometry mirror relative to incident light is difficult.

The problem of the above-described deterioration in focusing performance can be avoided to some extent, if, after the upper electrodes 602 are formed, the top  
15 face of the quartz substrate 608 is coated with a dielectric film having substantially the same refractivity as the upper electrodes 602, and this film is flattened.

Although the upper and lower electrodes 602, 601  
20 are symmetrical to the flexible thin film on the intermediate substrate, they may be asymmetrical in the same way, as described in the first embodiment.

For example, if the upper electrode 601 is composed of a single electrode opposing the entire  
25 range of the flexible thin film on the intermediate substrate while the electrostatic attracting force applied to the divided lower electrodes is differed

according on each position, the flexible thin film can be deformed unevenly.

(Sixth embodiment)

5 A sixth embodiment of the present invention will be described with reference to FIGS. 24A, 24B, 25A and 25B.

This embodiment adopts a two-layer structure by omitting the top substrate 103 of the first embodiment.

10 Its basic operating principle is the same as the above-described embodiment. Although it is incapable of controlling high-precision unevenness in the configuration, this embodiment is more advantageous since the number of electrodes can be reduced.

15 FIGS. 24A and 24B are perspective views of an upper face and a lower face showing the structure of a lower substrate 801 of a variable geometry cylinder mirror according to the sixth embodiment of the present invention.

20 FIGS. 25A and 25B are enlarged views taken in the direction of arrows A and B in FIG. 24A, indicating the assembly diagram of this embodiment.

These figures are represented in enlargement in the vertical direction to facilitate understanding.

25 Differences in terms of structure between this embodiment employing the two-layer structure and the three-layer structure of the first embodiment are as follows.



(1) Forming the intermediate substrate electrode lead-out pad on the top substrate and the Au bump formed thereon on the lower substrate.

5 (2) Connecting the intermediate substrate to the spacer member on the lower substrate.

Because the polyimide film side is joined to the spacer on the lower substrate, the installation direction is reverse to the three-layer structure.

10 (3) Thus, the Au thin film needs to be deposited on the side of the thin mono-crystal silicon substrate of the intermediate substrate as a reflection surface.

Thus, as described above, the present invention can provide a small variable geometry cylinder mirror which can be changed to a free configuration including an asymmetrical one.

15 Further, the present invention is capable of providing a variable geometry cylinder mirror which can be changed continuously from the concave face to the convex face and further which can be deformed with the center or any point in its reflection mirror portion fixed.

20 Further, the present invention can provide a variable geometry cylinder mirror which can obtain large changes in curvature with a relatively low voltage.

25 Additional advantages and modifications will readily occur to those skilled in the art. Therefore,

the invention in its broader aspects is not limited to  
the specific details and representative embodiments  
shown and described herein. Accordingly, various  
modifications may be made without departing from the  
5 spirit or scope of the general inventive concept as  
defined by the appended claims and their equivalents.